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NEURAL MODELS OF MOTION PERCEPTION

September 1, 1993—August 31, 1994
(Year 2 of 3)

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ABSTRACT

Six research projects supported by this grant during the reporting period have resulted in one published book chapter, one refereed article in press, two articles under review, and five conference publications. Areas of research included design and simulation of network architectures for: (1) spatial pooling and perceptual framing by synchronized cortical dynamics; (2) synthetic aperture radar processing by a multiple scale; (3) formation of cortical maps of ocular dominance and orientation columns; (4) a neuron model with variable ion concentrations; (5) a multi-scale model of brightness perception; and (6) models of motion perception.

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(An asterisk indicates publications for the current reporting period)

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RESEARCH SUMMARIES

1. Spatial Pooling and Perceptual Framing by Synchronized Cortical Dynamics [Articles 6, 7 and 14]

How does the brain group together different parts of an object into a coherent visual object representation? Different parts of an object may be processed by the brain at different rates and may thus become desynchronized. Perceptual framing is a process that resynchronizes cortical activities corresponding to the same retinal object. A neural network model was developed that is able to rapidly resynchronize desynchronized neural activities. Model properties quantitatively simulate perceptual framing data, including psychophysical data about temporal order judgments and the reduction of threshold contrast as a function of stimulus length. The model also exhibits better synchronization in the presence of noise than without noise, a type of stochastic resonance, and synchronizes robustly when cells that represent different stimulus orientations compete. The model utilizes fast long-range cooperative feedback that interacts with slow competitive feedback from inhibitory interneurons. Such a model has earlier been used to explain data about illusory contour formation, texture segregation, shape-from-shading, 3-D vision, and cortical receptive fields. The model hereby shows how all these data may be understood as manifestations of a cortical process that can rapidly resynchronize image parts which belong together in visual object representations.

2. Synthetic Aperture Radar Processing by a Multiple Scale Neural System for Boundary and Surface Representation [Article 11]

An algorithm based on an improved Boundary Contour System (BCS) and Feature Contour System (FCS) neural network vision model is developed to process images containing range data gathered by synthetic aperture radar (SAR) sensor. BCS/FCS processing makes structures such as motor vehicles, roads, and buildings more salient and interpretable to human observers than they are in the original imagery. Early processing by ON cells and OFF cells embedded in shunting center-surround networks normalizes input dynamic range and performs local contrast enhancement. Combining ON cell and OFF cell output in the BCS to define oriented filters overcomes complementary processing deficiencies of each cell type and improves sensitivity to image contours. The oriented filters output to stages of short-range competition and long-range cooperation that segment the image into regions by cooperatively completing and regularizing the most favored boundaries while suppressing image noise and weaker boundary groupings. Boundary segmentation is performed by three copies of the BCS at small, medium, and large scales, whose interaction distances covary with the size of the scale. Filling-in of surface representations occurs within the FCS at each scale via a diffusion process. Diffusion is activated by the normalized FCS inputs and restricted to the compartments defined within each BCS boundary segmentation. The three scales of surface representation are then added to yield a final multiple-scale output.

3. Formation of Cortical Maps of Ocular Dominance and Orientation Columns [Article 12]

Three computational rules are sufficient to generate model cortical maps that simulate the interrelated structure of cortical ocular dominance and orientation columns: a noise input, a spatial band pass filter, and competitive normalization across all feature dimensions.

The data of Blasdel from optical imaging experiments reveal cortical map fractures, singularities, and linear zones that are fit by the model. In partiuclar, singularities in orientation preference tend to occur in the centers of ocular dominance columns, and orientation contours tend to intersect ocular dominance columns at right angles. The model embodies a universal computational substrate that all models of cortical map development and adult function need to realize in some form.

4. A Neuron Model with Variable Ion Concentrations [Article 13]

Voltage is the central focus of most models of the single neuron. Recently interest in long-term potentiation (LTP) has surged, due to its linked to learning. It has been shown that LTP is accompanied by an increase of the internal calcium concentration. Prior models have included provision for variable calcium concentrations, but since the calcium concentration in these models is typically very low, it has a negligible effect on the membrane potential. In the present model all ion concentrations are variable due to ionic current and due to ion pumps. It is shown that this significantly increases the complexity of neural processing, and thus variable ion concentrations cannot be ignored in neurons with high firing frequency, or with very long depolarizations.

5. A Multi-Scale Network Model of Brightness Perception [Articles 17 and 18]

A model is developed to account for a wide variety of difficult data, including the classical phenomenon of Mach bands, low- and high-contrast missing fundamental and nonlinear contrast effects associated with sinusoidal luminance waves. The model builds upon previous work by Grossberg and colleagues on *filling-in models that predict* brightness perception through the interaction of *boundary* and *feature* signals. Simulations of the model implement a number of refinements already described in the development of Grossberg's (1987, 1994) Form-And-Color-And-DEpth (FACADE) theory, which though conceived as part of the theory, were not implemented in the simulations of Grossberg and Todorović (1988). These include: (a) ON and OFF channels with separate filling-in domains; (b) multiple spatial scales; (c) revised computations for simple and complex cells; and (d) boundary computations that engage a recurrent competitive circuit. Simulations of the present system of equations account for human's perception of a wide variety of stimuli, including ones whose brightness contains shallow spatial gradients.

6. Models of Motion Perception [Article 8]

This encyclopedia article reviews the major historical data on human visual motion perception and describes classical attempts to model motion detection. It then describes recent developments in a more comprehensive model, called the Motion Boundary Contour System, proposed by Grossberg and colleagues.

STUDENT SUPPORT

Clark Dorman, Alexander Grunewald, Gregory Lesher, David Pedini, and Jeff Yuan, graduate students in the Department of Cognitive and Neural Systems, received support during the first two years of the grant.

Lesher received his PhD degree in Cognitive and Neural Systems in May, 1993. The topic of his dissertation was "Neural networks for vision and pattern recognition: Boundary completion, spatial mapping, and multidimensional data fusion." He is currently working as a systems engineer for Enkidu Research of Ithaca, New York.

Dorman, Grunewald, and Yuan continue to work towards the completion of a PhD degree.

Pedini applied for a one-semester leave of absence beginning in September, 1994.